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TECHNICAL MEMORANDUM

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DISTORTION MEASUREMENTS ON BANDPASS FILTERS WITH POWDERED IRON TOROIDAL INDUCTORS

A. SARTI

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TECHNICAL MEMORANDUM
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Distortion Measurements on Bandpass Filters with Powdered Iron Toroidal Inductors

SUMMARY

This paper reports the results of measurements of both in-band and out-of-band non-linear distortion for an 11 - 18 MHz bandpass filter which used powdered iron toroidal cores for the inductors. The results are compared with those from a bandpass filter of the same specification using air cored inductors. It is shown that a performance comparable in linearity to the air cored inductor case can be obtained with appropriately sized powdered iron toroidal cores, while still realising to some extent the advantages of magnetic self shielding and smaller volume that are usually associated with the use of toroidal cores.

Jan 92

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CONTENTS

FIGURES

TABLES

APPENDICES

FIGURES

1 INTRODUCTION

High frequency radar places stringent requirements on the linearity of the components of the receiving subsystems in order to reduce the effects of intermodulation distortion arising from high level interfering signals in the HF environment.

The worst distortions arise from third order intermodulation of the out-of-band interferers which produce products in the radar signal band and which therefore cannot be reduced by subsequent filtering. In general it is not possible to completely protect the front end of the receiver against third order distortion by bandpass filtering, since interference can occur anywhere. However, it is possible in principle to protect the receiver from second order distortion products by using sub-octave filters with adequate specifications.

This paper was stimulated by a particular application in which the Mini-Radar receiver in the Jindalee Radar Frequency Management System had to be protected against second order intermodulation distortion (IMD). The mini-radar system was a low power backscatter radar used to evaluate ionospheric doppler shift as an aid to frequency management of the main Jindalee radar, and also to acquire an environmental database for research into ionospheric propagation. As much receiving hardware integrity as possible was required in both roles - in particular, for the purpose of this paper, the mini-radar receiver was preceded with a set of four low insertion loss sub-octave bandpass filters. A complete description of the Jindalee Frequency Management system is given by Earl and Ward, 1987, reference [1].

The requirements for the sub-octave filters were as follows:

(a) The switch control for the filters allowed only four filters to be used to cover the HF band from 4 to 30 MHz;

(b) The estimate of the HF interference environment dictated stop-band attenuations of 60 dB or more;

(c) The filters themselves had to be very linear so as not to introduce non-linear distortion internally.

These requirements dictated complex bandpass filters with rapid attenuation into the stop-band, and as a routine measure, construction using air-cored inductors and silvered mica capacitors for linearity. The actual units built performed well around the pass-band and for a reasonable way into the stop-band, and then exhibited poor attenuation around 40-50 MHz because of the effects of distributed stray capacitance and inductance as shown in Figure 10. This defect was corrected by using an additional low pass filter in series with the switched filter bank. The overall response and linearity were good but the final unit was quite large and the solution to the stray problem was not particularly elegant.

Since powdered iron toroids are routinely used for the cores of inductors in filters, it was natural to pursue the question of obtaining the benefits of small size with low strays and yet still achieve high levels of linearity. A reasonable framework within which to undertake measurements was the filter specification for the mini-radar receiver and this paper therefore reports the results and conclusions of linearity and frequency response measurements made on one particular filter in the set (covering the sub-octave range 11 - 18 MHz) using a variety of toroidal cored inductors. In the subsequent discussion the powdered iron toroidal cores will be referred to simply as toroids.

Some investigative work has been performed previously by Rafuse, reference [2], comparing air-cored and toroidal inductors with respect to linearity, but not in the desired context and quantitative approach required in this case.

2 FILTER CHARACTERISTICS

The mini-radar bandpass filter subsystem is shown in Figure 1. As described in Appendix A, 2-mesh Elliptic filters were necessary to achieve the specified sub-octave performance in terms of pass and stop bandwidths. The filter covering the range from 11 to 18 MHz was chosen, somewhat arbitrarily, as an example for the investigation.

The filter using air-cored inductors had 2nd and 3rd order non-linearities measured by Input Intercept Points (IIP) of >100 dBm and >60 dBm respectively.

3 MEASUREMENT EQUIPMENT

3.1 Two-tone combiner

In order to measure the 2nd and 3rd order distortion of the filter, a test circuit was needed to provide two spectrally pure signals with 2nd and 3rd order distortion less than expected from the filters under test. The system had to be wideband in nature, since in-band and out-of-band intermodulation products were to be measured. The system used is shown in Figure 2. It comprised two signal generators FS1 and FS2 feeding into a combining network C, which produced the composite signal:-

$$V_{sig} = V_1 \sin(\omega_1 t) + V_2 \sin(\omega_2 t) \qquad (1)$$

and then into a variable attenuator. The attenuator was used to vary the signal level entering the Filter Under Test (FUT).

A short description of the components of the test set and their function follows.

1. FS1 and FS2 are identical 1-160MHz Fluke Frequency Synthesisers model 6160B. They are characterised by their low phase noise, better than -115 dB at an offset frequency of 1.2kHz measured in a 1Hz bandwidth, and good signal to noise ratio of greater than 94 dB measured in a 30KHz bandwidth.

2. C is a combining network.

3. A1 is a Hewlett Packard model 355c VHF attenuator. It is variable from 0 to 12 dB in increments of 1 dB.

4. FUT are the 11-18MHz bandpass filters.

The combining network had the specific purpose of combining two tones in the HF band with minimal generation of 2nd and 3rd order products. It consisted of two identical branches of filtering and gain stages leading to a 2-way combiner unit, as shown in Figure 3.

Each signal branch consisted of a 20 dB pad feeding a high reverse isolation amplifier with 30 dB forward gain. The pad was to ensure the amplifier was not overdriven. Following the amplifier were a set of three harmonic rejection filters covering the frequency range 5 to 28MHz, followed by a 6 dB matching attenuator feeding into one port of the 2-way combiner.

The objective of this combining network structure was to ensure high isolation between the two signal sources FS1 and FS2 and thereby reduce the 2nd and 3rd order products produced in the non-linear output stages of the signal sources. A more detailed explanation of the circuit design and theory and limits of perormance are given in reference [3].

3.2 Spectrum Analyser Input Filter

Care had to be taken to prevent the first mixer in the spectrum analyser from generating distortion products comparable to those expected from the toroid filters.

This requirement was met by lowpass filtering the two tones and upper 3rd order product at the spectrum analyser input, and measuring only the lower frequency 3rd order product.

In order to accommodate a combination of test frequencies without requiring a new lowpass filter for every measurement, the 2f1-f2 term was assigned a fixed frequency while the f1 and f2 terms were varied in different combinations allowed by the filtering and gain in the combining network. A lowpass filter of low complexity was achieved by forcing the lowest 3rd order product to be near the low cut-off of the bandpass filter under test and restricting the tones to be at least 3MHz above the low frequency product. The filter chosen for this was a Chebyshev lowpass filter with cut-off frequency of 11.5MHz, 0.5 dB ripple and at least 18 dB of attenuation at the lowest tone frequency. The 18 dB of attenuation was sufficient to reduce spurious products in the spectrum analyser to negligible levels. The filter was constructed using air-cored inductors and silvered mica capacitors for linearity. Circuit diagram and specifications are shown in Figure 4.

3.3 Spectrum Analyser Input Filter Performance

A series of 3rd order intermodulation tests were performed on the input lowpass filter using a variety of in-band and out-of-band test frequencies, in order to determine the upper limit of the measuring system. Results are shown in Table 1, with the set-up as shown in Figure 5. In all cases, a check was made to see that the distortion was being introduced by the filter and not by the spectrum analyser. The final column in Table 1 displays the maximum Input Intercept Point (IIP) measurable for the different test frequencies.

Table 1 Spectrum analyser input filter distortion products

Test Frequencies (MHz)		Distortion Products for various input levels (dBm)		Max IIP (dBm)
F_1	F_2	0	+2	
14.2	17.1	-118.0	-112.2	+59.0
14.6	17.9	-124.5	-118.7	+62.3
17.1	22.9	-124.0	-118.0	+62.0
15.5	19.7	-120.5	-114.5	+60.3
19.1	26.9	-123.0	-117.4	+61.5
20.1	28.9	-123.3	-118.0	+61.7

The distortion levels produced by the test set and lowpass filter were expected to be well below the levels from the toroidal filters being tested.

4 TOROIDAL INDUCTOR FILTERS

The selection of toroidal cores for high frequency inductors is governed by the following factors:

(a) a large Al value (defined by the manufacturers, relating the inductance to the number of turns squared) to reduce the number of turns for a given inductance and hence reduce coil losses

(b) low loss material allowing high Q to be achieved

The toroidal cores available at the time of the measurements came from the Micrometals range. Four cores of different sizes were selected as suitable for the inductance and Q ranges required. These are specified in Table 2.

Table 2 Toroid Specifications

Toroid	Outer Diameter (Inch)	Inner Diameter (Inch)	Height (Inch)	Inductance per 100 turns (μH)
T-30-2	0.307	0.151	0.128	43
T-44-10	0.440	0.229	0.159	35
T-50-10	0.500	0.303	0.190	31
T-80-10	0.795	0.495	0.250	34

The toroidal inductor filters were comfortably housed in die-cast aluminium boxes of dimensions (115mm x 90mm x 52mm), half the volume of those used for the air-cored inductor filter (170mm x 115mm x 52mm).

Figures 6 to 9 show the behaviour of the four filters built with the four core sizes above, over the frequency range 10Hz to 300MHz. The high frequency attenuation has been maintained at a higher level in the toroidal inductor filters than was possible with the air-cored inductor filter as shown in Figure 10.

5 RESULTS OF DISTORTION MEASUREMENT

A series of 2nd and 3rd order IMD tests were performed on the filters in both in-band and out-of-band cases with the test circuit as shown in Figure 11. The results for the 3rd order case are listed in Table 3(a) and Table 3(b) and show the air-cored inductor filter produced the smallest level of IMD. The distortion produced in the toroidal cored inductor filters decreased as the toroid volume increased as expected. The results have been adjusted to take into account the attenuation of the LPF at 11.3MHz.

Table 3a. 3rd Order IMD for 0 dBm I/P

Test Frequencies (MHz)		Distortion Product for 0 dBm Input level (dBm)				
F_1	F_2	Air	T-80-10	T-50-10	T-44-10	T-30-2
14.2	17.1	<-118.0	<-118.0	-114.3	-104.9	-97.0
14.6	17.9	<-124.5	<-124.5	-111.3	-105.5	-98.0
17.1	22.9	<-124.0	<-124.0	-122.3	-118.3	-116.2
15.5	19.7	<-120.5	<-120.5	-112.5	-109.3	-104.1
19.1	26.9	<-123.0	<-123.0	<-123.0	-122.7	-120.5
20.1	28.9	<-123.3	<-123.3	<-123.3	-122.5	-120.0

Table 3b. 3rd Order IMD for +5 dBm I/P

Test Frequencies (MHz)		Distortion Product for +5 dBm Input Level (dBm)				
F_1	F_2	Air	T-80-10	T-50-10	T-44-10	T-30-2
14.2	17.1	-114.5	-112.2	-97.8	-89.2	-80.3
14.6	17.9	-119.3	-117.1	-95.5	-90.1	-81.0
17.1	22.9	-120.5	-117.9	-110.1	-104.3	-99.7
15.5	19.7	-115.1	-110.2	-98.3	-96.3	-94.1
19.1	26.9	-119.1	-114.2	-113.0	-108.8	-105.9
20.1	28.9	-118.0	-115.0	-112.2	-108.5	-105.4

The 2nd order IMD test results are listed in Table 4(a) and Table 4(b) and for all test frequencies the distortion originated in the combining network. The differences in IMD levels were due to differences in the input impedance of the bandpass filters, and in all cases the LPF at the output was not required since at least one of the test tones was out-of-band. A complete second order intercept analysis of the combining network is listed in reference [3], with results ranging between 100 to 115 dbm.

Table 4a. 2nd Order IMD for 0 dBm I/P

Test Frequencies (MHz)		Distortion Product for +0 dBm Input Level (dBm)				
F_1	F_2	AIR	T-80-10	T-50-10	T-44-10	T-30-2
5.5	5.8	-113.2	-113.0	-116.9	-115.7	-116.7
6.4	17.7	-120.1	-122.5	-118.3	-119.5	-121.6
16.9	28.2	<-125.0	<-125.0	<-125.0	-123.1	<-125.0
14.2	25.5	-121.6	<-125.0	-123.5	<-125.0	-122.5

Table 4b. 2nd Order IMD for +5 dBm I/P

Test Frequencies (MHz)		Distortion Product for +5 dBm Input Level (dBm)				
F_1	F_2	Air	T-80-10	T-50-10	T-44-10	T-30-2
5.5	5.8	-107.8	-107.5	-111.5	-110.3	-111.8
6.4	17.7	-114.5	-117.3	-112.4	-113.9	-115.9
16.9	28.2	-122.0	-122.3	-124.1	-117.6	-122.2
14.2	25.5	-116.0	-121.7	-118.1	-124.1	-116.8

Table 5 summarises the results for 3rd order Input Intercept Points.

Table 5. 3rd Order IIP

Test Frequencies (MHz)		Third Order Input Intercept Point (dBm)				
F_1	F_2	Air	T-80-10	T-50-10	T-44-10	T-30-2
14.2	17.1	>+59.0	>+59.0	+56.0	+51.5	+47.6
14.6	17.9	>+62.3	>+62.3	+55.0	+52.0	+48.2
17.1	22.9	>+62.0	>+62.0	+61.2	+59.2	+58.1
15.5	19.7	>+60.3	>+60.3	+56.3	+54.7	+52.1
19.1	26.9	>+61.5	>+61.5	>+61.5	+61.4	+60.3
20.1	28.9	>+61.7	>+61.7	>+61.7	+61.3	+60.0

6 CONCLUSION

The third order intercept measurements are summarised in Table 5. From the results obtained it was evident that the air-cored inductor filter out-performed the smaller toroidal inductor filters with reference to 3rd order IMD. The 2nd order IMD products were not measurable but were all better than a specified level ranging between 100 to 115 dbm. The best performing toroidal inductor filter was the largest one, T-80-10, which had performance in most cases only 2 to 3 dB below the level of the air-cored filter.

The inductors using the larger toroidal cores showed some very significant advantages over the air-cored inductors, for a small penalty in 3rd order distortion. The size could be reduced by a very large factor and also the self shielding and low strays allowed the theoretical filter characteristics to be met up at the high frequency range.

The measurements reported in this paper show that provided the larger toroids are used, filters with close to theoretical behaviour, high linearity, and relatively small size (compared to air-cored inductor filters), can be achieved.

REFERENCES

1. G. F. Earl and B. D. Ward. 'The Freqency Management System of the Jindalee Over-The-Horizon Backscatter HF Radar.', Radio Science., vol 22, p.275, March-April 1987.

2. R.P. Rafuse 'Factors Pertinent to the Design of Wide Dynamic Range Receivers & Transmitters.' Massachusetts Institute of Technology, December 1970.

3. P. C. Kerr. 'A Measurement System for the Characterisation of High Frequency Receiver Nonlinearity.' SRL-0072-TN , March 1992.

4. A. Zverev 'Handbook of Filter Synthesis', J. Wiley & Sons, 1967.

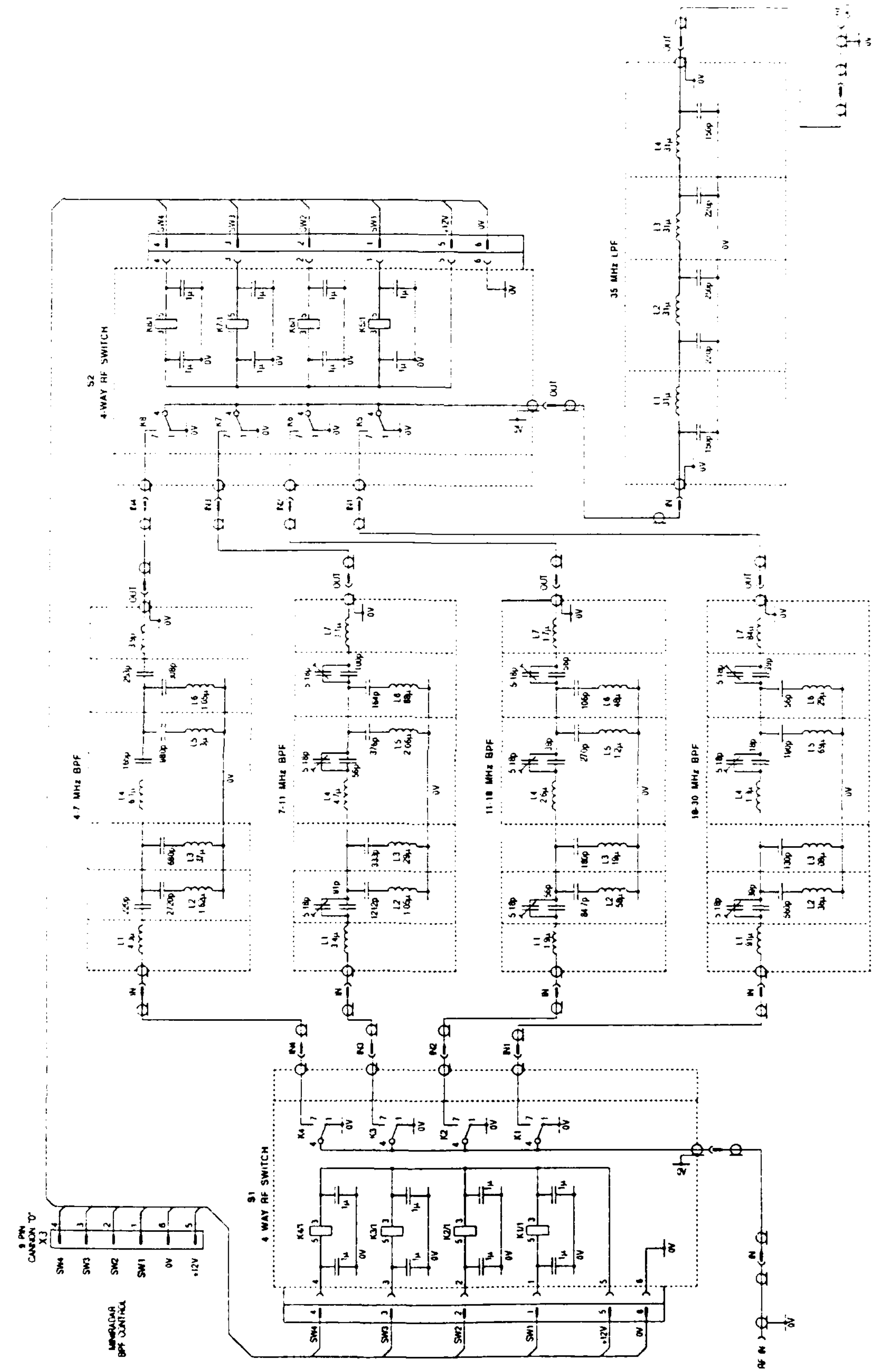


Figure 1. Mini Radar Bandpass Filters

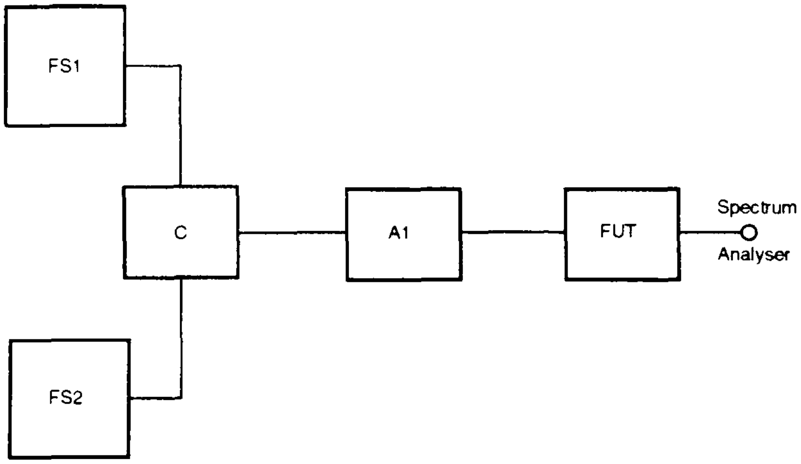


Figure 2. Test Circuit

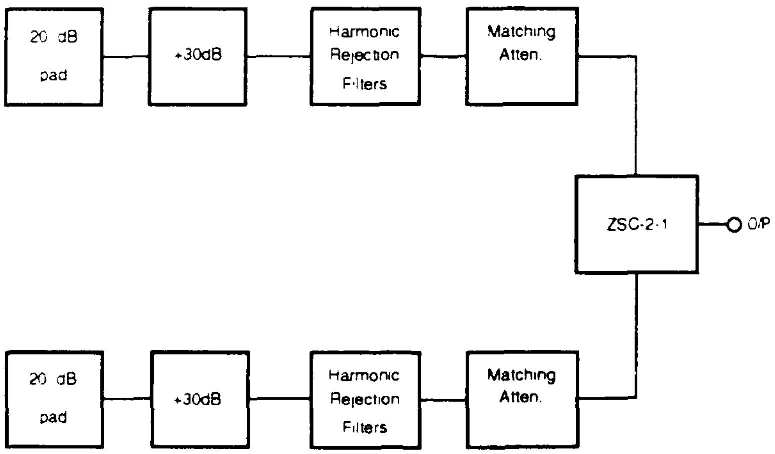
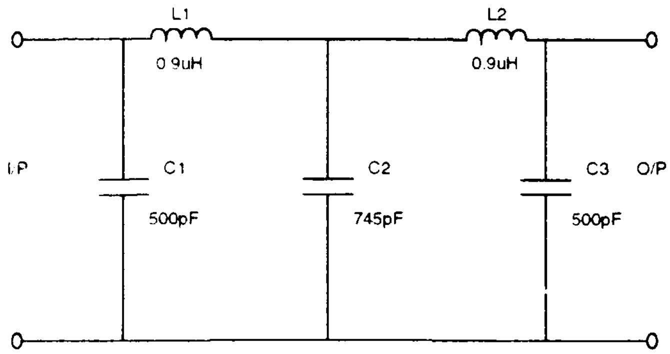


Figure 3. Combining Network



F kHz	Loss dB	F kHz	Loss dB	F kHz	Loss dB	F kHz	Loss dB
5750.000	0.1	10062.500	0.2	14375.000	19.0	18687.500	34.3
6181.250	0.1	10493.750	0.3	14806.250	20.9	19118.750	35.5
6612.500	0.1	10925.000	0.9	15237.500	22.7	19550.000	36.7
7043.750	0.2	11356.250	2.5	15668.750	24.4	19981.250	37.8
7475.000	0.3	11787.500	4.8	16100.000	26.0	20412.500	38.9
7906.250	0.4	12218.750	7.5	16531.250	27.6	20843.750	40.0
8337.500	0.5	12650.000	10.1	16962.500	29.0	21275.000	41.0
8768.750	0.6	13081.250	12.5	17393.750	30.4	21706.250	42.0
9200.000	0.6	13512.500	14.9	17825.000	31.8	22137.500	43.0
9631.250	0.4	13943.750	17.0	18256.250	33.1	22568.750	44.0

Figure 4. Output LPF

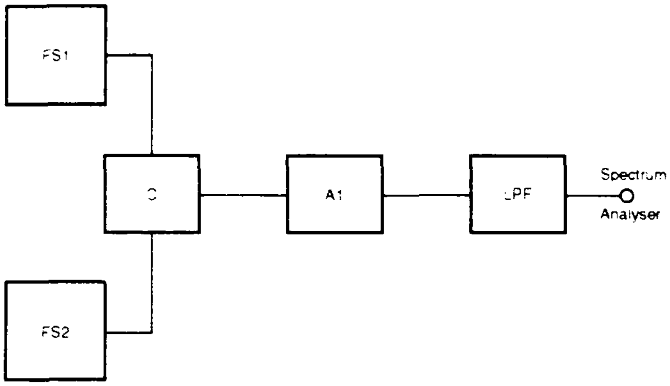


Figure 5. LPF Test Circuit

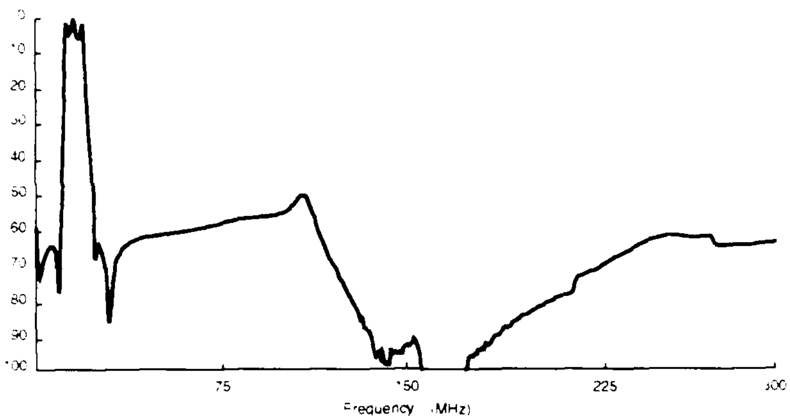


Figure 6. Magnitude Response - BPF : T-30-2

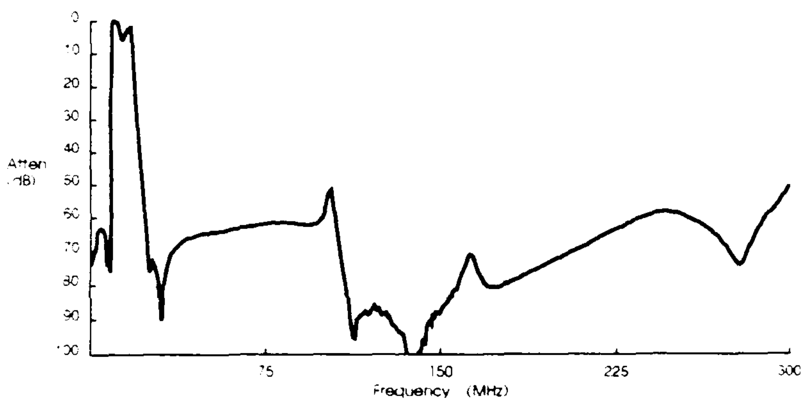


Figure 7. Magnitude Response - BPF: T-44-10

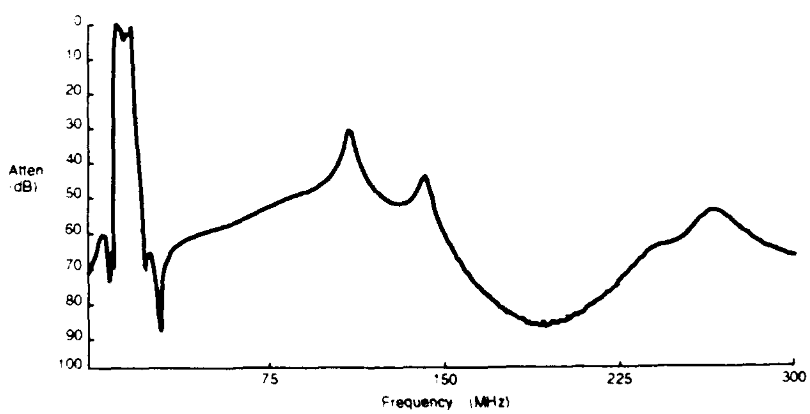


Figure 8. Magnitude Repsonse - BPF: T50-10

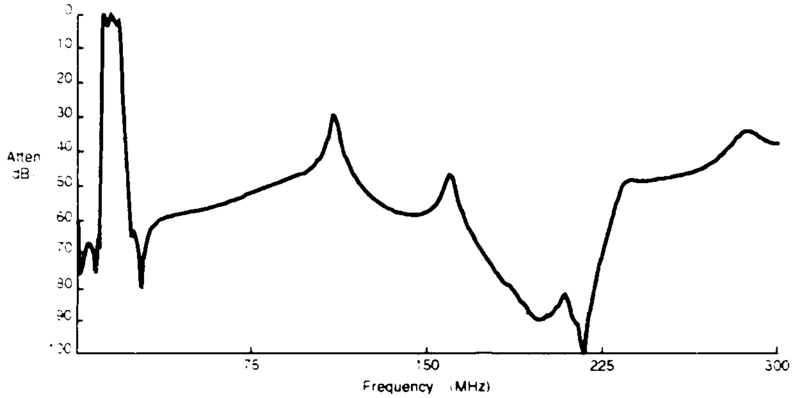


Figure 9. Magnitude Response - BPF: T-80-10

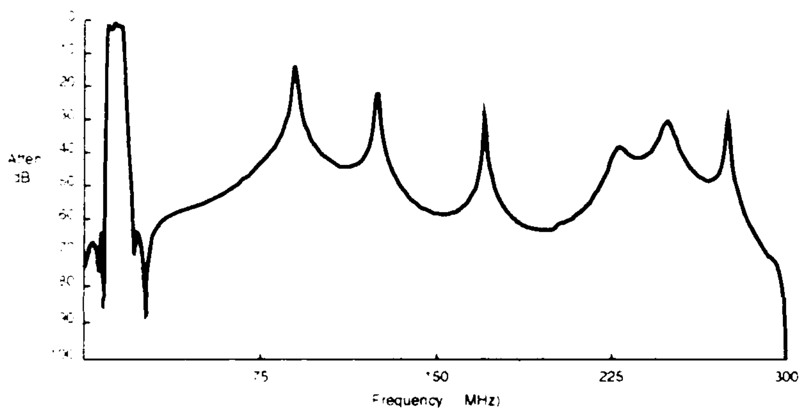


Figure 10. Magnitude Response - BPF : Air Cored

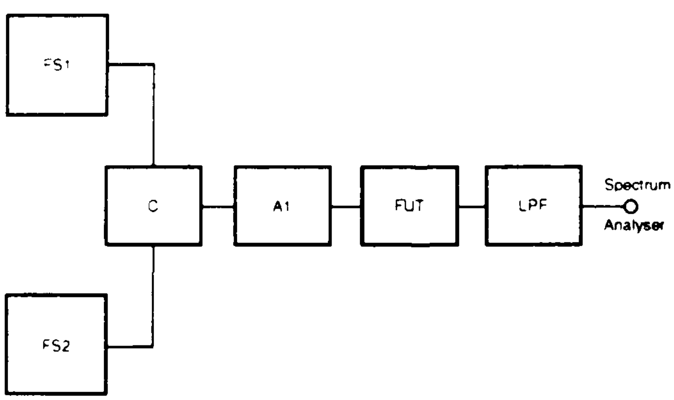


Figure 11. Final Test Circuit

APPENDIX A Selection of Sub-Octave Filter Bandwidths.

Assume four filters are sufficient to provide the specified sub-octave filtering across the 4-30 MHz band, and let the bandwidths be selected in geometric progression as shown in Figure A-1 where the lowest frequency, (f_1), is 4 MHz and the upper cut-off of the top filter, ($k^4 f_1$), is 30 MHz.

ie. $$f_1 = 4 \qquad \text{(A1)}$$

$$k^4 f_1 = 30 \qquad \text{(A2)}$$

giving $$k = 1.655 \qquad \text{(A3)}$$

and hence the required filter bands are:

1. 4-7 MHz
2. 7-11 Mhz
3. 11-18 MHz
4. 18-30 MHz **(A4)**

As illustrated in Figure A-2 the filter shape factor to 60 dB, (S_{60}), is determined by the requirement that the filter attenuation at the second harmonic of the low cut-off frequency, and at half the upper cut-off frequency, must be 60 dB. This level of attenuation was dictated by FMS environmental analysis.

Hence,

$$S_{60} = \frac{(2 - k/2)}{(k-1)} = 1.79 \qquad \text{(A5)}$$

From tables of Elliptic filters [4] two-mesh elliptic bandpass filters can be selected to meet the requirements.

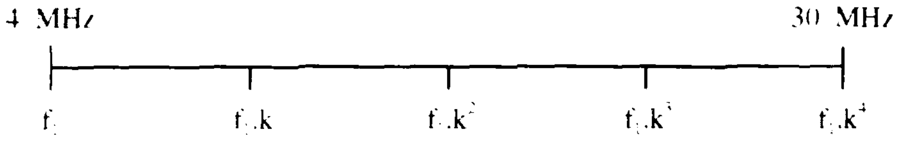


Figure A-1 Determination of the Four Sub-Octave Filters

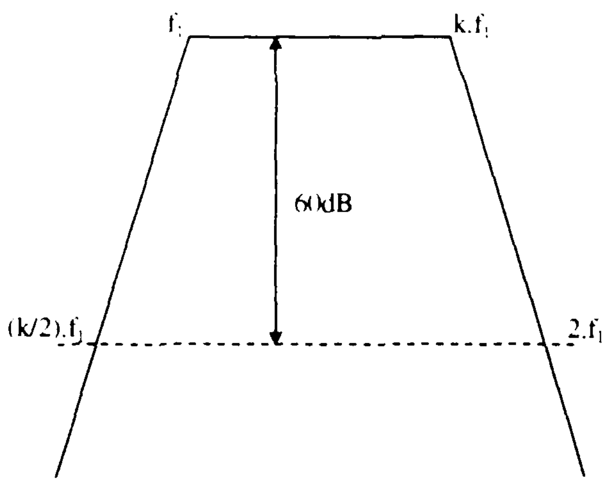


Figure A-2 The Shape Factor to 60 dB

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Electric coils
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Measurement

b. Non - Thesaurus Terms

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17 SUMMARY OR ABSTRACT
(if this is security classified, the announcement of this report will be similarly classified)

(U) This paper reports the results of measurements of both in-band and out-of-band non-linear distortion for an 11 - 18 MHz bandpass filter which used powdered iron toroidal cores for the inductors. The results are compared with those from a bandpass filter of the same specification using air cored inductors. It is shown that a performance comparable in linearity to the air cored inductor case can be obtained with appropriately sized powdered iron toroidal cores, while still realising to some extent the advantages of magnetic self shielding and smaller volume that are usually associated with the use of toroidal cores.